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Theoretical and Experimental Determination of the Muscle Strength for the Kinetotherapy Rehabilitation of the Elbow Joint after an Immobilization Period

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Abstract

This paper analyzes the main motion of the forearm used also to kinetotherapy recovery: the flexion-extension, with high amplitude, this way it was adopted hypothesis of a fixed arm and a flexed forearm, with angles from the horizontal position, 0°, 50° and 120°. Experimental measurements aimed to determine changes in muscle strength biceps during flexion forearm through direct electro-myographic evaluation of muscle activity of the biceps muscle.

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Keywords: kinetotherapy rehabilitation, goniometer, EMG

1. Introducion

The elbow joint rehabilitation after an immobilization period, involves conducting controlled motion exercises of the forearm, in order to restore elasticity, all soft tissue and joint capsule for regaining normal contraction forces the forearm muscles that provide movement. Elbow joint connects the arm and forearm, allowing hand-body distance control and hand positioning in space (Hamilton & Luttgens, 2002). By mobilizing the joints is essential movements of everyday life made the food, hygiene, defense, etc. Functional division of this joint makes the flexion-extension movement to control the hand position in the sagittal plane and pronation-supination by moving the control to achieve transverse plane.

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Research on post-traumatic joint recovery of the upper member, after consulting the literature were divided into three categories, namely: studies on anatomical and physiological aspects of human upper limb, the general features of the osteo-articular system the whole body segments arm - forearm, in particular, studies on biomechanical modeling, kinematics and dynamics of the human upper limb, the technical applicability (robotics, for example) or medical (medical recovery, for example) or the biomechanical characteristics of mechanical strength of tissue components of the upper limb kinematic or dynamic human studies and structural and functional descriptions of technical systems used in the rehabilitation of post-traumatic joint upper member (Abdel-Malek, 2004).

In this article a theoretical analysis is performed on the virtual model and can be considered correct because mechanical loading system in the forearm was well chosen and determined from calculations, experimental measurements confirming the theoretical assumptions (Reinkensmeyer et al., 2004). At the same time experimental measurements were made that allowed simultaneous correlation of three parameters: the angle of flexion-extension, pronation-supination angle and the biceps muscle activity by EMG, being determined more precisely, muscle strength values at the considered flexion angles in the theoretical analysis on the virtual model. Theoretical and experimental values obtained were finally compared (Hesse et al., 2003; Leugmair et al., 2008).

2. Theoretical considerations on the rehabilitation of joint forces

The main movement of the forearm, used to recover physical therapy, is the flexion-extension, of high amplitude, so that has been adopted the assumption of a fixed arm and a forearm flexed out, with angles from the horizontal, 0° , 50° and 120°. In fig. 1a) it is noted that on the forearm, to ensure the movement it was considered that it is acting the biceps muscle force, Fm, and for an active rehabilitation it was considered a gravity force, Fg, with values ranging from 5 [N] and 50 [N].

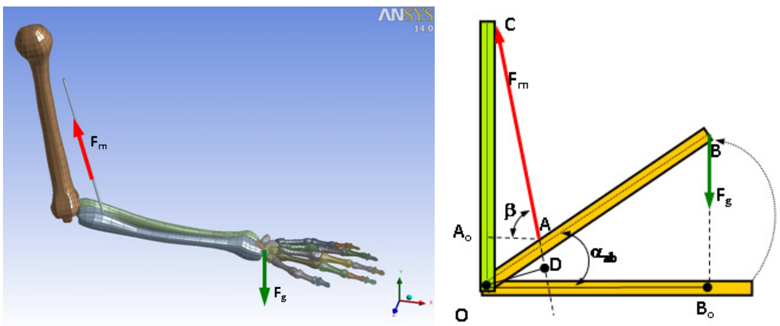


Fig. 1. Schematic representation of a) applied forces of forearm and b) forearm flexion under the action of applied forces

If we assume that on the forearm only act these two applied forces, the equation of equilibrium of moments, written to the elbow joint, can determine the expression of muscle strength calculation, the equation of equilibrium and the final expression is:

$$F_m \cdot L_{OD} - F_g \cdot L_{OB_o} = 0 \tag{1}$$

where:

$$F_m = \frac{F_g \cdot L_{OB_o}}{L_{OD}}. \tag{2}$$

Distances L_{OD} and L_{OB_o}, respectively the distances from points O and D, and O and Bo, represented in Figure 2, are the arms of the two forces to a reference point, coinciding with the geometrical center of the elbow joint for flexion-extension movement. If it is considered the forearm flexion angle α_{ab}, and the angle that the biceps muscle force is making with the horizontal plan, we can write the trigonometric relationship in the triangle (A_oAC):

$$tg\beta = \frac{A_oC}{A_oA} \tag{3}$$

where: $A_oC = L_b - L_{OA_o}$, $A_oA = L_A \cdot \cos\alpha_{ab}$, $L_{OA_o} = L_A \cdot \sin\alpha_{ab}$, L_A - the distance between the geometric center of the elbow joint (O) and forearm insertion point of the biceps muscle.

Relation (5.3) can be written as:

$$tg\beta = \frac{L_b - L_A \cdot \sin\alpha_{ab}}{L_A \cdot \cos\alpha_{ab}} \tag{4}$$

where muscle force angle can be calculated, at any time of the forearm flexion.

Based on geometrical considerations the following equations can be written:

$$L_{OB_o} = L_{ab} \cdot \cos\alpha_{ab} \quad (5)$$

$$L_{OD} = \frac{L_b \cdot L_A \cdot \cos\alpha_{ab}}{L_b - L_A \cdot \sin\alpha_{ab}} \cdot \sin\beta \quad (6)$$

where: L_b, L_{ab} - are arm's length, respectively the forearm.
Using relations (5) and (6), muscle strength, Fm, from equation (2) is written as:

$$F_m = F_g \cdot \frac{L_{ab} \cdot \cos\alpha_{ab} \cdot (L_b - L_A \cdot \sin\alpha_{ab})}{L_b \cdot L_A \cdot \cos\alpha_{ab} \cdot \sin\beta} \quad (7)$$

Graphical representation of muscle strength variation, Fm, depending on the force of gravity used to the medical recovery, Fg, according to relation (7), several angles of flexion of the forearm (0º, 50º, 120º) and for a patient with 1.71 [m] height, is given in Fig. 2. A negative value of muscle strength, which is shown in Figure 5.9, indicates the direction of force respectively in opposition to the positive values.

Table 1 shows the angle values calculated with equation (4) for a patient with a 1.71 [m] height, where: $L_b = 0.188 \cdot H = 0.321$ [m], $L_{ab} = 0.145 \cdot H = 0.145 \cdot 1.71 = 0.247$ [m], $L_A = 0.2 \cdot L_{ab} = 0.049$ [m],
In Table 2 are presented muscle strength values determined by the equation (7).

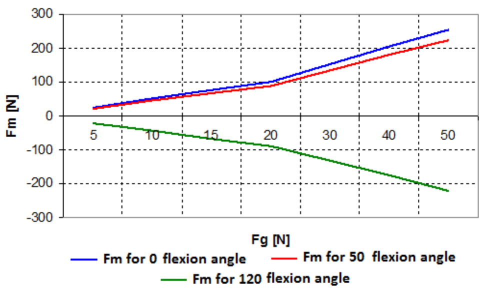


Fig. 2. Variation of muscle strength

Tab. 1. Angle of muscle strength

α_{ab} [º]	β [º]
0	81.32091
50	83.65969
120	-84.9737

Tab. 2. The biceps muscle force

α_{ab} [º]	F_g [N]	F_m [N]
0	5	25.49604
	10	50.99207
	15	76.48811
	20	101.9841
	30	152.9762
	40	203.9683
	50	254.9604
50	5	22.39381
	10	44.78762
	15	67.18143
	20	89.57524
	30	134.3629
	40	179.1505
	50	223.9381
120	5	-21.9566
	10	-43.9132
	15	-65.8698
	20	-87.8264
	30	-131.74
	40	-175.653
	50	-219.566

Using these forces allowed the determination of the state of stress and strain in the elbow joint bones in the forearm, using the finite element method. Mechanical tensions determined are compared with allowable values so that they can be evaluated continuously during rehabilitation sessions, the mechanical strength of bone.

3. Experimental determinations

For a muscle, healthy, in a state of relaxation, it cannot be recorded a significant EMG activity, due to the lack of depolarization and action potential. EMG signal peaks are of random shapes, which mean that a record cannot be reproduced exactly as shape. This is because the motor units continuously change in relation to their diameter. In the event that two or more motor units act at the same time, and they are located near the electrodes, these muscles produce overlapping peaks (which may overlap). Applying a smoothing algorithm or selecting an appropriate amplitude parameter (eg, area under the corrected curve), irreproducible nature of the signal can be eliminated or at least minimized.

Between muscle membrane and electrodes, EMG signal can be influenced by several external factors that can change its shape and characteristics. These factors are grouped into the following categories:

- tissue characteristics: the human body is a good conductor, but its electrical conductivity varies with tissue type, density, its temperature and the physiological changes;

- physiological influence: neighboring muscles can produce a significant amount of EMG signal is detected at the electrodes, normally this influence does not exceed 10-15% of the total signal or not occur at all but it still should be considered for muscle groups;
- changes in geometry of the heart muscle and electrode position: any change in the distance between the original signal and the detection location will change reading EMG;
- external noise: special care must be taken for high electrical noise environments;
- electrodes and amplifiers: selection / quality of the electrodes and the internal amplifier can increase the content of EMG baseline, internal amplifier noise must not exceed certain imposed values.

Most of these factors can be minimized by appropriate training and checking of laboratory conditions. After obtaining the EMG signal to determine the development of muscular strength it is necessary to perform an integration schedule electric potential muscle (EMG), knowing that muscle strength is proportional to the area enclosed by EMG signal and the horizontal axis time.

Experimental measurements aimed to determine strength variation of the muscle biceps during flexion the forearm through direct electromyographic evaluation of muscle activity of the biceps muscle.

Experimental tests were performed on a total of 3 volunteers, two of whom were male, using surface electromyography electrodes (cutaneous) and goniometric transducers to determine the flexion-extension angle of the forearm. Also it was used a specialized software electromyographic signal tracing and graphical integration of the signal. Experimental recordings were performed at the Faculty of Medical Bioengineering, Laboratory of Electrophysiology, University of Medicine and Pharmacy "Grigore T. Popa".

Measurement chain consisted of the following components: superficial cutaneous electromyography electrodes (drop the biceps muscle) data acquisition board, two electronic goniometric for angles determination of flexion-extension and pronation-supination and computer with specialized software (MicroImage and Acquanowledge). Schematic representation of the measurement chain is given in Figure 3a).

Electromyographic signal, picked up by electrodes placed on the biceps muscle was amplified and taken by a data acquisition card and recorded on a computer. Stored signal was then processed with specialized software, resulting from changes in muscle strength numerical integration. Electrodes were placed in the muscle center area so that electromyographic signal to be relevant (Fig. 3 b)). Variation curve of the biceps strength, experimentally determined to be compared with the previously analytically obtained one for human subject H = 1.71 [m] and M=76 [kg].

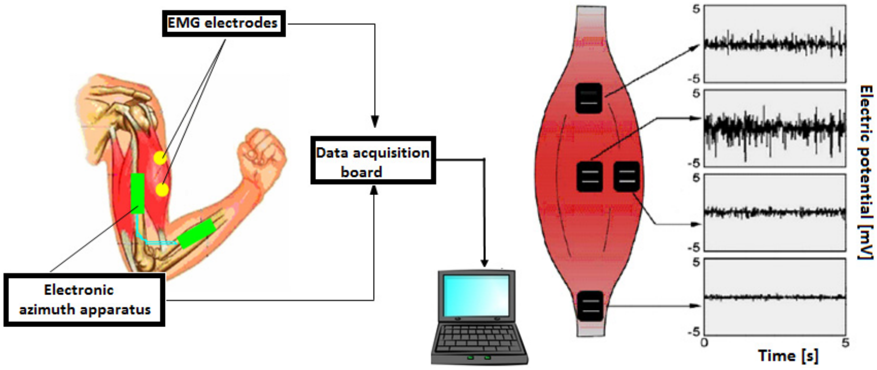
Test subjects arm and forearm were supported on a stand specially built, with the possibility of adjusting the height and angular position with no arm movement, but in a comfortable position. Support arm immobilization was achieved with several textile straps. In Fig. 4 a) there is a partial view of the immobilization frame with one arm of the test subjects attached to the support, and in Fig.4 b) presents a partial picture during experimental testing. Electromyographic signals for the biceps muscle activity during flexion-extension and goniometry the recordings regarding the variation of the flexion-extension angle and pronation-supination were appropriate to the subject with height H = 1.71 [m]. The biceps muscle force resulting from processing EMG signal, through its integration and quantification in units of force. Moving from voltage units (milli-volts) to units of force (Newtons) was achieved by calibrating electrical signal using a dynamometer. Thus, using rehabilitation orthosis with loads of 0.5 [kg], 1 [kg] and 1.5 [kg], the results of the dynamometer and maximum electrical signal were:

- at 0,05 [mV] it was measured a force to dynamometer of 25 [N], for a hand held mass of 0,5 [kg];
- at 0,11 [mV] it was measured a force to dynamometer of 45 [N for a hand held mass of 1 [kg];
- at 0,09 [mV] it was measured a force to dynamometer of 72 [N], for a hand held mass of 1,5 [kg].

In these circumstances, it appears that at 1 [mV] we have the following forces corresponding to the three specified loads: 500 [N] 409 [N] and 800 [N]. If three values are averaged it means that for 1 [mV] electromyographic signal will correspond to a force of 569, 66 [N]. Therefore, the calibration constant is: ke = 569.66 [N / mV].

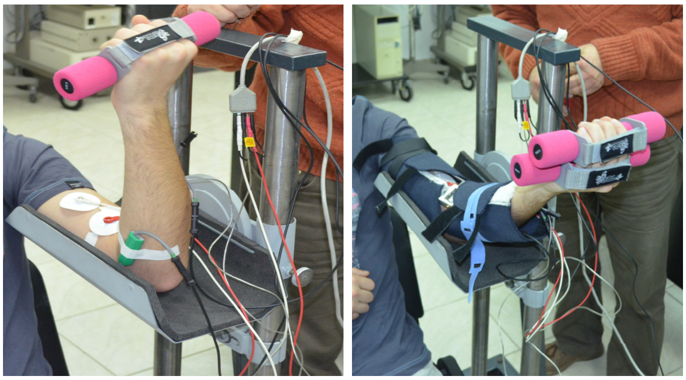
The values obtained are shown in Table 3, given at the same time, theoretical values used to analyze the virtual model (see table 2). Comparing the graphs between them experimentally and theoretically obtained for each angle of flexion in part you can find the following:

- at flexion angle of 0°, graph theoretical of strength variation has the same allure that of experimentally determined force, theoretical force values are higher than those obtained experimentally;
- at flexion angle of 50°, the two graphs almost coincide;
- at flexion angle of 120°, the differences are obvious, but the graphics allure remains.



a) b)

Fig. 3 Schematic representation of a) measuring chain, b) placement of electrodes on muscles



a) b)

Fig.4 a) The support and immobilization of the forearm, b) image during experimental testing

Tab. 3. The biceps muscle force, experimental and theoretical

α_{ab} [º]	Fg [N]	Experimental Fm [mV]	Experimental Fm [N]	Theoretical Fm [N]
0	5	0.028	15.95048	25.49604
	10	0.083	47.28178	50.99207
	15	0.096	54.68736	76.48811
50	5	0.041	23.35606	22.39381
	10	0.094	53.54804	44.78762
	15	0.08	45.5728	67.18143
120	5	0.051	-29.05266	-21.9566
	10	0.104	-59.24464	-43.9132
	15	0.088	-50.13008	-65.8698

4. Conclusions

From the representation of the flexion-extension movement, and pronation-supination movement, appropriate signals are captured from two electronic goniometrics and at movement of the forearm electromyogram signal is provided by miografic electrodes. Following experimental research on muscle strength in the biceps muscle, which controls the forearm flexion, when orthotics rehabilitation of the elbow joint is used, it could be highlighted the following aspects.

The designed orthosis with two degrees of freedom, has proven its worth during the experiment by in allowing the forearm, outside flexion and supination additional movement, resulting in motion of several muscle groups, exercises for medical recovery, the use of additional movements shortens the muscle-articular rehabilitation. Rehabilitation orthosis has the advantage of allowing the kinetotherapist setting flexion-extension angular amplitude of the forearm so that the patient starts the medical recovery from low angle of flexion, to the normal maximum values.

Rehabilitation and orthosis stand used in electromyographic measurements presents advantages for the use in conjunction at post-traumatic rehabilitation exercises of the elbow joint, the stand, made by us, has linear adjustments, vertical and horizontal, and angular adjustments that allow patients of different sizes to adjust the arm during exercise in as comfortable position.

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